INTRODUCTION TO THE CDIO APPROACH TO ENGINEERING EDUCATION

–

MOTIVES, IMPLEMENTATION AND EFFECTS ON EDUCATIONAL QUALITY

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OUTLINE

- **What is CDIO?**
- **Case: CDIO in Chalmers' mechanical engineering programme**
- **Impact of CDIO implementation on educational quality**

WHAT IS CDIO?

- **An idea of what engineering students should learn and how: To become "Engineers who can engineer"**
- **A methodology for engineering education reform: The CDIO Syllabus and the 12 CDIO Standards**
- **A community: The CDIO Initiative with 120+ universities as members**

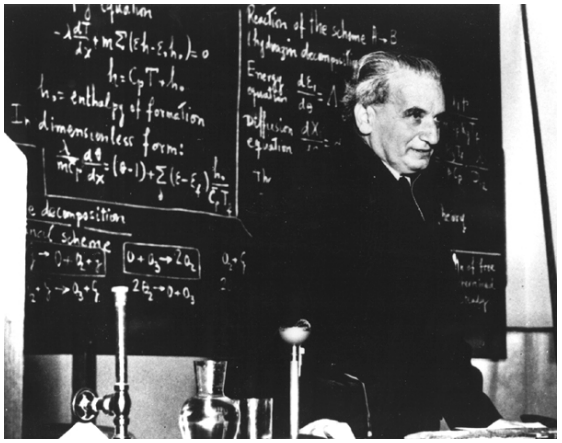
THE IDEA IN CDIO

WHAT SHOULD ENGINEERING STUDENTS LEARN?

HOW SHOULD THEY LEARN IT?

THE PROFESSIONAL ROLE OF ENGINEERS

”Scientists investigate that which already is. Engineers create that which has never been.
- Theodore von Karmann



”What you need to invent, is an imagination and a pile of junk”
- Thomas Edison

THE CDIO DEFINITION

”Engineers Conceive, Design, Implement and Operate complex products and systems in a modern team-based engineering environment”

THE C-D-I-O PROCESS

Lifecycle of a product, process, project, system, software, material

Conceive: customer needs, technology, enterprise strategy, regulations; and conceptual, technical, and business plans

Design: plans, drawings, and algorithms that describe what will be implemented

Implement: transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation

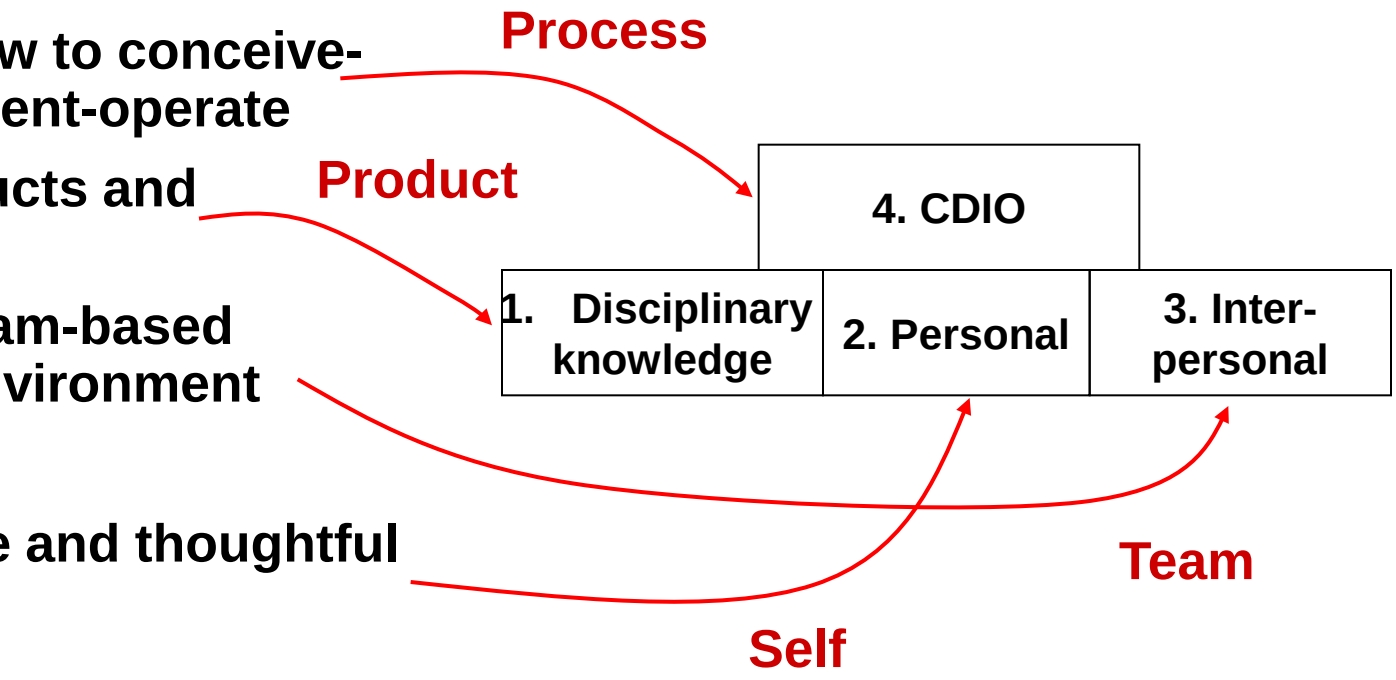
Operate: the implemented product or process delivering the intended value, including maintaining, evolving and retiring the system

Duke University

FROM UNDERLYING NEED TO PROGRAM LEARNING OUTCOMES

Educate students who:

- **Understand how to conceive-design-implement-operate**
- **Complex products and systems**
- **In a modern team-based engineering environment**
- **And are mature and thoughtful individuals**



The CDIO Syllabus - a comprehensive statement of detailed goals for an engineering education

THE CDIO SYLLABUS 2.0

- **A generalized list of competences that an engineer should possess**
- **Program specific (1) and general (2-4)**
- **Created and validated by alumni, faculty and students**
- **A ”complete” reference model**

1 Disciplinary Knowledge & Reasoning:
- 1.1 Knowledge of underlying mathematics and sciences
- 1.2 Core engineering fundamental knowledge
- 1.3 Advanced engineering fundamental knowledge, methods and tools

2 Personal and Professional Skills
- 2.1 Analytical reasoning and problem solving
- 2.2 Experimentation, investigation and knowledge discovery
- 2.3 System thinking
- 2.4 Attitudes, thought and learning
- 2.5 Ethics, equity and other responsibilities

3 Interpersonal Skills
- 3.1 Teamwork
- 3.2 Communications
- 3.3 Communication in a foreign language

4 CDIO of Complex Systems
- 4.1 External, societal and environmental context
- 4.2 Enterprise and business context
- 4.3 Conceiving, systems engineering and management
- 4.4 Designing
- 4.5 Implementing
- 4.6 Operating
- 4.7 Leadership
- 4.8 Entrepreneurship

CDIO Syllabus contains 2-3 more layers of detail

VISION FOR A CDIO-BASED EDUCATION

An education that stresses the fundamentals, set in the context of Conceiving – Designing – Implementing – Operating systems and products:

- **Clear, detailed programme learning outcomes that express a holistic view of engineering**
- **A curriculum organised around mutually supporting courses, with CDIO activities highly interwoven**
- **Rich with student design-build projects**
- **Integrating learning of professional skills such as teamwork and communication**
- **Featuring active and experiential learning**
- **Taught by teachers with scientific, engineering and pedagogic competence**
- **Constantly improved through quality assurance process with higher aims than accreditation**

NEED FOR REFORM

Retask current assets and resources in:

- **Curriculum**
- **Teaching and learning methods**
- **Design-implement experiences and engineering workspaces**
- **Learning assessment methods**
- **Faculty competence**
- **Program evaluation**

A systematic approach is needed to address these issues!

THE CDIO EDUCATION DEVELOPMENT METHODOLOGY

CDIO DEVELOPMENT METHODOLOGY

- **CDIO syllabus –** ***WHAT***
- **CDIO standards –** ***HOW***
- **CDIO curriculum design process –** ***from WHAT to HOW***
- **CDIO standards self-evaluation –** ***HOW WELL***

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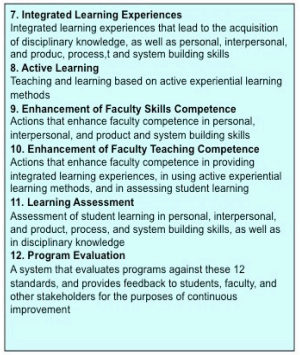
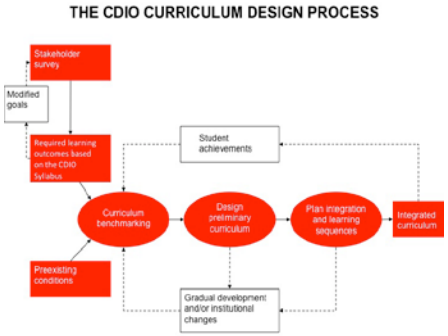
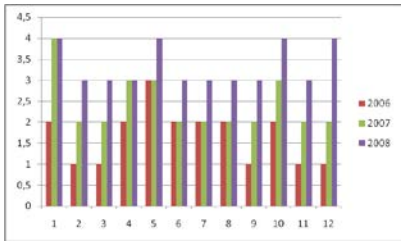
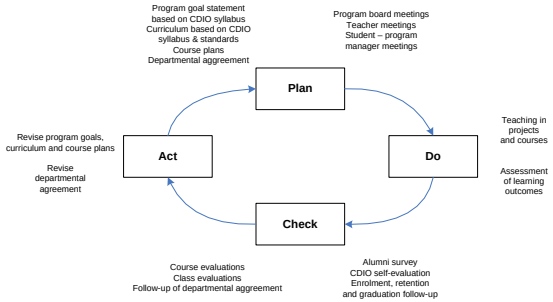
1. The Context
Adoption of the principle that product. Process, and system lifecycle development and deployment are the context for engineering education
2. Learning Outcomes
Specific, detailed learning outcomes for personal, interpersonal, and product,.process and system building skills, consistent with program goals and validated by program stakeholders
3. Integrated Curriculum
A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product, process, and system building skills
4. Introduction to Engineering
An introductory course that provides the framework for engineering practice in product. Process, and system building, and introduces essential personal and interpersonal skills
5. Design-Implement Experiences
A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level
6. Engineering Workspaces
Workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning



7. Integrated Learning Experiences
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and produc, process,t and system building skills
8. Active Learning
Teaching and learning based on active experiential learning methods
9. Enhancement of Faculty Skills Competence
Actions that enhance faculty competence in personal, interpersonal, and product and system building skills
10. Enhancement of Faculty Teaching Competence
Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning
11. Learning Assessment
Assessment of student learning in personal, interpersonal, and product, process, and system building skills, as well as in disciplinary knowledge
12. Program Evaluation
A system that evaluates programs against these 12 standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement







THE 12 CDIO STANDARDS – THE GUIDELINES FOR CDIO DEVELOPMENT

Context & golals 1,2	• CDIO as Context • CDIO Syllabus Outcomes
CDIO curriculum & space 3,4,5,6	• Integrated Curriculum • Introduction to Engineering • Design-Build Experiences • CDIO Workspaces
Teaching & Learning 7,8	• Integrated Learning Experiences • Active Learning
Faculty development 9,10	• Enhancement of Faculty CDIO Skills • Enhancement of Faculty Teaching Skills
Evaluation 11,12	• CDIO Skills Assessment • CDIO Program Evaluation

CASE:

MECHANICAL ENGINEERING AT CHALMERS UNIVERSITY OF TECHNOLOGY, SWEDEN

PLANNING THE CHANGE AT CHALMERS

Identify needs & opportunities for change	***Strengths*** + More • Project-based courses • Design courses ***Weaknesses*** • No design-build-test projects, lack of authenticity • Employer requested better communication skills, project leadership & initiative + More • Poor links between maths and engineering subjects
Establish vision & strategy	CDIO was selected as basis for a program vision & strategy
Identify early successes	4th year design-build-test competition-based projects were focused (Formula Student, Autonomous vehicles)
Set up system for measuring the change	Self-assessment vs CDIO standards

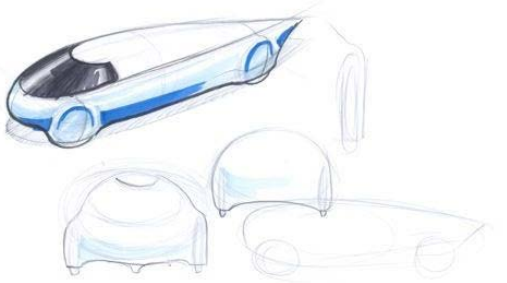
DESIGN-IMPLEMENT EXPERIENCES

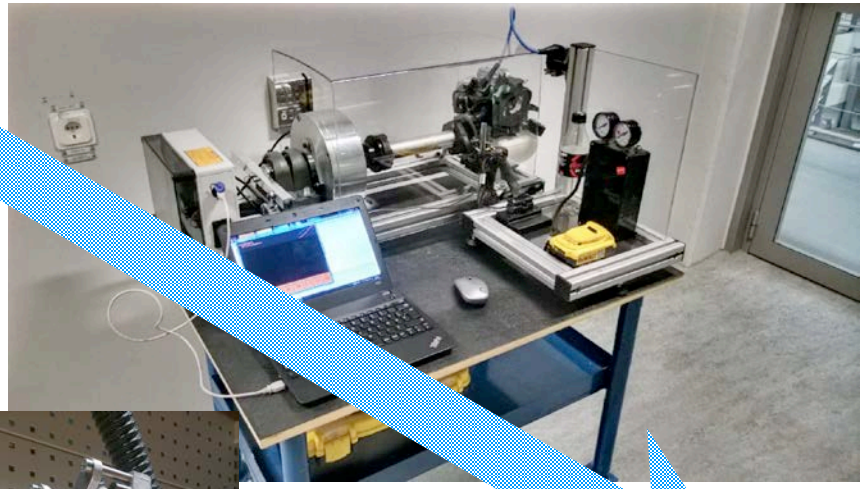
Design-implement experiences are instructional events in which learning occurs through the creation of a product, process, or system

- **Train authentic engineering and decision-making**
- **Provide the natural context in which to teach many CDIO syllabus skills (teamwork, communications, designing, implementing)**

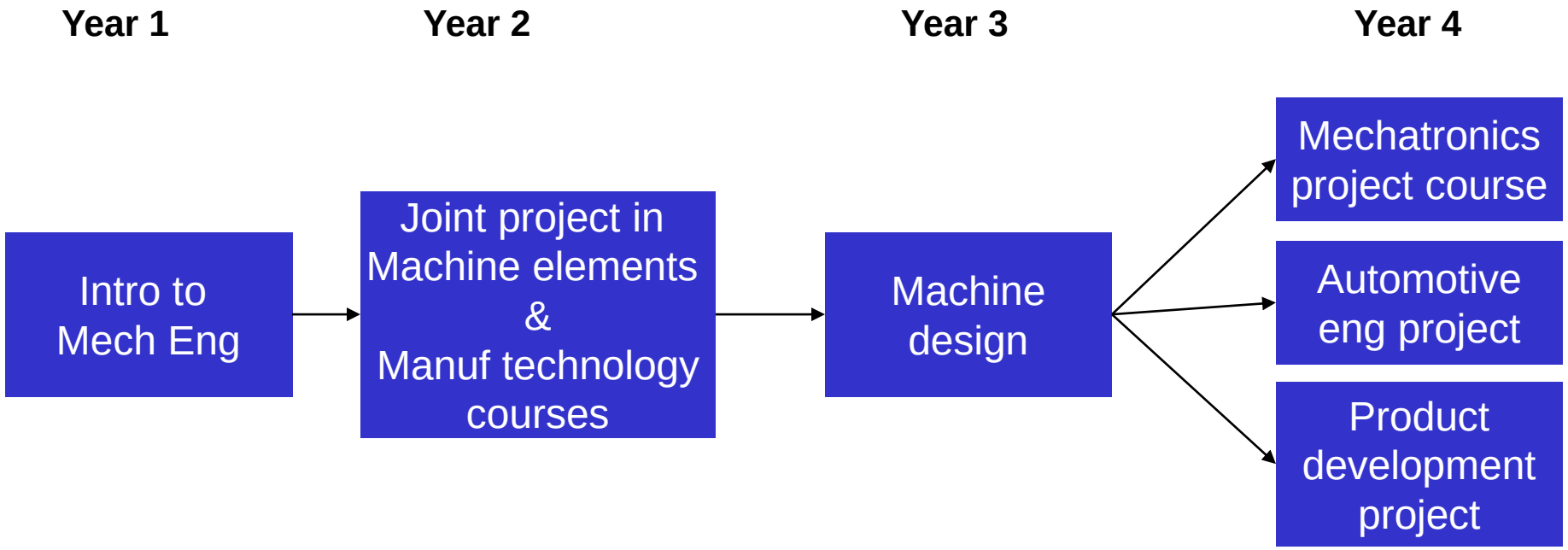
DESIGN-BUILD-TEST PROJECT EXAMPLE

Chalmers
Eco-Marathon Vera





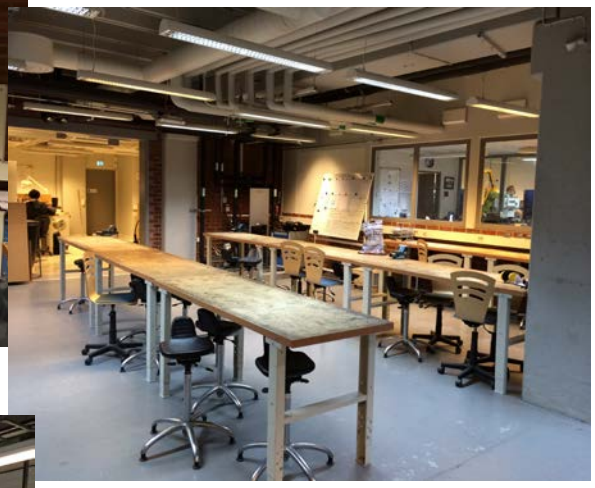
A PLANNED LEARNING SEQUENCE FOR DESIGN SKILLS

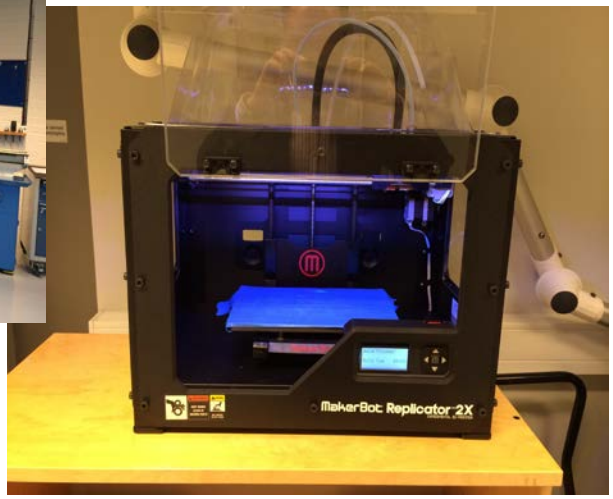


Year 1	Year 2	Year 3	Year 4
Creative, ”conceptual” design	Design for manufacturing	Redesign Multiple objectives	Creative design incl business aspects Cross-dept teams
Simple prototype Qualitative	More advanced prototype Some simulation Company is customer	Prototype as needed More simulation	Prototype Simulation as needed Company is customer

THE PROTOTYPING LABORATORY

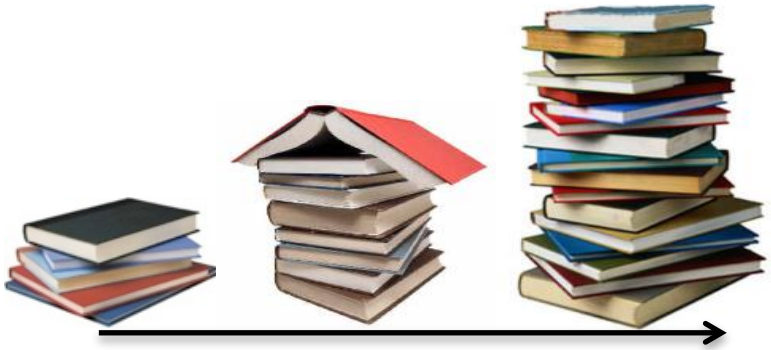
- 450 m2 facility where students can build prototypes
- Metal machining, woodworking, rapid prototyping, waterjet welding, electronics, composites (soon) …
- Used in courses and projects from year 1 to master thesis projects





INTEGRATED LEARNING EXPERIENCES

Integrated learning experiences develop **both** technical knowledge and “generic” skills (communication, teamwork, ethics, sustainability, etc)



Acquisition of technical knowledge

Development of generic skills

Source: Kristina Edström

INTEGRATED CURRICULUM YEAR 1-3

Year 1

Intro Mathematics 7.5 ECTS	Single-variable Calculus 7.5 ECTS	Linear Algebra 7.5 ECTS	Several-variable Calculus 7.5 ECTS
Programming in Matlab 4.5 ECTS	CAD M[illegible]hp	Mechanics and Solid Mechanics I 7.5 ECTS	Mechanics and Solid Mechanics I I 7.5 ECTS
Intro to Mechanical Eng 7.5 ECTS			

Year 2

Mechanics and Solid Mechanics I II 7.5 ECTS	Machine Elements 7.5 ECTS	Integrated Design and Manufacturing Project 7.5 ECTS	
Materials 7.5 ECTS	Materials and Manufacturing Technology 7.5 ECTS	Sustainable product development 4.5 ECTS	Industrial Production & Org 6 ECTS
		Thermodynamics 7.5 ECTS	Industrial Economics 4 ECTS

Year 3

Mechatronics 7.5 ECTS	Control Engineering 7.5 ECTS	Bachelor Thesis Project 15 ECTS	
Fluid Mechanics7.5 ECTS	Elective I 7.5 ECTS	Elective II 7.5 ECTS	Mathematical Statistics 7.5 ECTS

- **Common computation labs in mathematics, programming & engineering science**
- **Communications**
- **Teamwork**
- **Sustainability**
- **Ethics**
- **Integrative project in design & manufacturing**

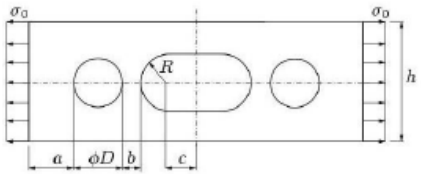
REFORMED MATHEMATICS EMPHASIZING SIMULATIONS

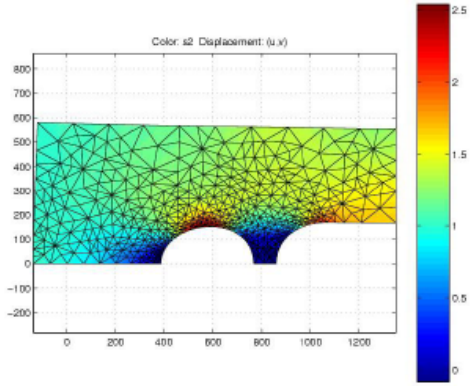
- **Motivate importance of mathematics and applied mechanics courses**
- **Realistic engineering problems**
- **Working method based on modelling, simulation & analysis**
- **MATLAB programming**
- **Visualization of mechanical behaviour**

Year 1 lab example

Analys av plan elastiska skiva med fyra hål

Beräkna spänningskoncentrationsfaktorn. Avgör om spänningshöjningarna vid hålen samverkar. Symmetrier skall utnyttjas.





A SYSTEM FOR CONTINUOUS IMPROVEMENT

Revise program description
and course plans
Sign the agreement
for next year's course delivery

ACT

PLAN

Program description
Course plans
Jointly taught projects
Advisory board
Teachers meetings
Student – program manag. meetings

Course evaluations
Class evaluations
Follow-up of agreem.
Alumni survey
Self-assessment
Benchmarking
Student results follow-up
Safety and health review,
Study social review

CHECK

DO

Teach in courses
and projects.
Assessment
and examination of learning outcomes

A CULTURE OF CHANGE

Pre CDIO	CDIO planning	CDIO basic design & piloting	CDIO implementation	CDIO +
-2000	2000-2001	2001-2004	2004-2008	2009-2013
M2000 reform • Project courses • More design • Early eng experiences • Master-like profiles • No design-build-test	• Set project goals • Concretize CDIO concept • Bench-marking • Design-build-test pilots	• Prototyping lab • Multiple design-build-test projects • Integrated learning • 3+2 education structure adapted	• Mathematics • Sustainability • Bachelor project • English on master level • HSV Excellence center	• Virtual learning environment for math stat • Integrated sustainability Material science courses with product focus • Set new goals • Visiting committee

CURRENT FOCUS

- **Entrepreneurship for the few and for the many**
- **New technologies**
- **Preparing for global collaboration and competition**
- **Ethics**
- **Blended learning**
- **Challenge-based learning experiences**
- **Composites fabrication**
- **…**

SOME RECOGNITION

The ME programme was evaluated as ***very high quality*** in the 2013 Swedish national evaluation

UNIVERSITETS-KANSLERSÄMBETET
Swedish Higher Education Authority

Engineering programme of the year 2012, Swedish Industry Association

ÅRETS TEKNIK UTBILDNING 2012

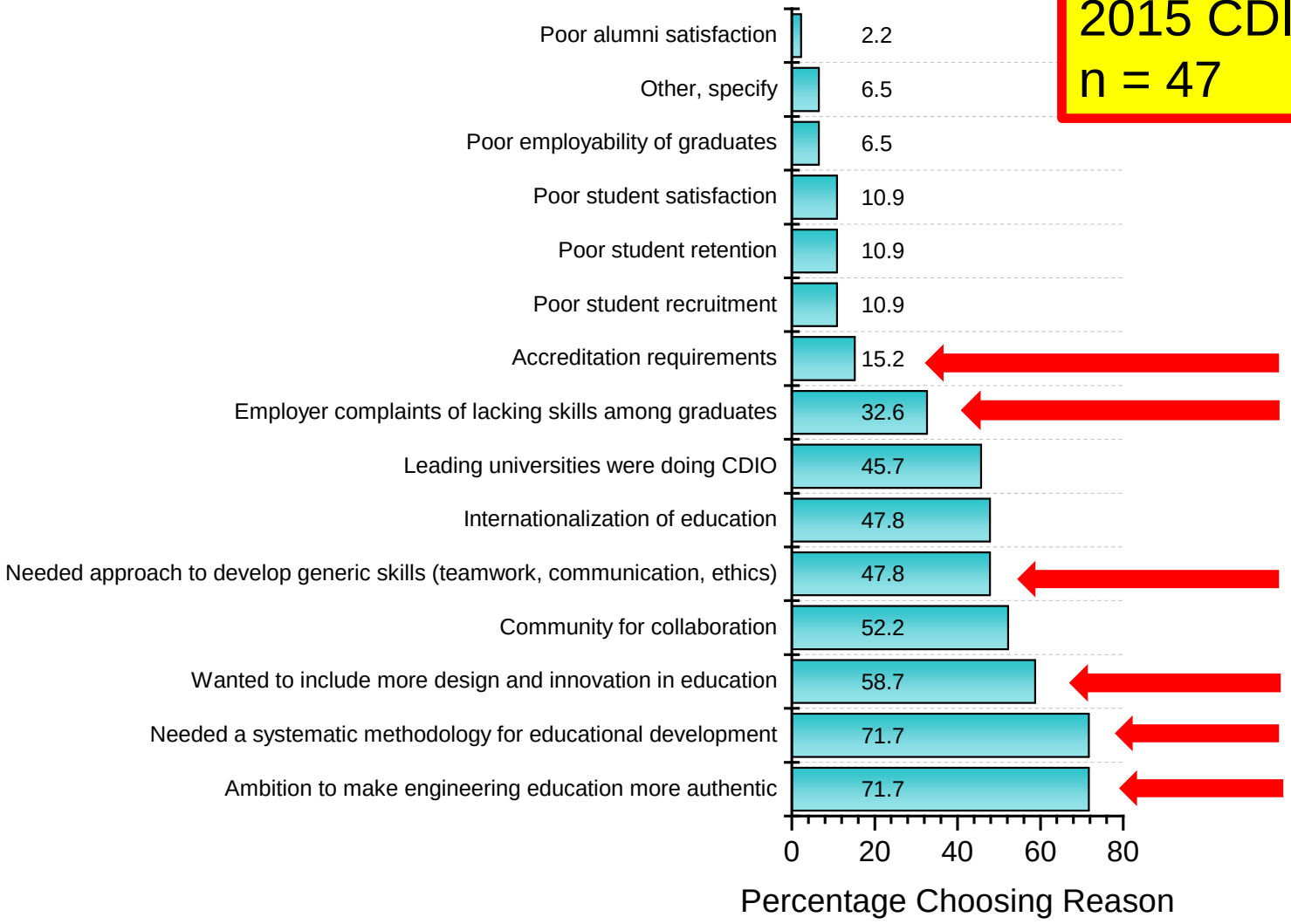
Center of excellence in higher education 2008, National Agency of higher education

RAMSTÅENDE UTBILDNINGSMILJÖ 2008
Centre of Excellence in Higher Education
HÖGSKOLEVERKET
Swedish National Agency for Higher Education

EFFECTS OF CDIO IMPLEMENTATION ON EDUCATIONAL QUALITY?

MOTIVES FOR ADAPTING CDIO

2015 CDIO survey, n = 47



Focused in this presentation

Malmqvist, Hugo & Kjellberg, 2015

EFFECTS (SELECTED)

Strong agreement	Neutral agreement	Disagreement
Improved CDIO skills	Improved faculty professional comp	Weakened maths & science knowlegde
Improved inter-personal skills	Improved student recruitment	
Quality awards & recognition	Improved student retention	
More collaboration w other uni's	Required large investments	
Improved personal skills	Raised operating costs	

APPLYING CDIO TO PREPARE FOR ACCREDITATION REVIEW

- **The ABET, EUR-ACE, … accreditation standards/criteria are "WHATS", ie they do not say how a particular criteria should be addressed**

- **The CDIO standards are "HOWS" which address about ¾ of the ABET or EUR-ACE requirements**

TABLE 3.3 THE CDIO SYLLABUS CORRELATED WITH ABET'S EVALUATIVE CRITERION 3

CDIO Syllabus	ABET's Evaluative Criterion 3									
	a	b	c	d	e	f	g	h	i	j	k
1.1 Knowledge of Underlying Mathematics, Science	■										
1.2 Core Engineering Fundamental Knowledge	■										
1.3 Adv. Engr. Fund. Knowledge, Methods, Tools	▒										■
2.1 Analytical Reasoning and Problem Solving					■						▒
2.2 Exper. Investigation and Knowledge Discovery		■									
2.3 System Thinking			▒								
2.4 Attitudes, Thought, and Learning								■			
2.5 Ethics, Equity, and Other Responsibilities						■					▒
3.1 Teamwork				■							
3.2 Communications							■				
3.3 Communication in Foreign Languages											
4.1 External, Societal, and Environmental Context			▒					■		■	
4.2 Enterprise and Business Context											
4.3 Conceiving, Systems Engr., and Management			■								
4.4 Designing			■								
4.5 Implementing			▒								
4.6 Operating											
	■ Strong Correlation						▒ Good Correlation				

ABET Criteria	Elements	CDIO standard
4. Continuous improvement	Documented processes that assess and evaluate that intended student outcomes are attained.	11, 12
	Systematic use of results from evaluation processes to improve program	
	Use of other data to improve programme	

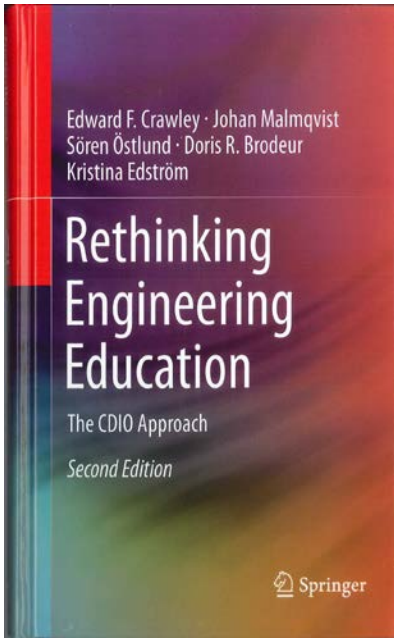
CDIO APPLICATION TO PREPARE FOR ACCREDITATION (EXAMPLES)

Country	University	Discipline	Year	Agency
USA	US Naval Academy	Aerospace		ABET
	MIT	Aerospace		ABET
Australia	Uni Sydney	Electrical	2009	Engineers Australia
Portugal	ISEP	Informatics	2012	EUR-ACE
Singapore	Singapore Polytechnic	Chemical	2012	IChemE
	Nanyang Polytechnic	Aerospace	2013	ABET
Sweden	Chalmers UT	All	2013	HSV
Vietnam	Duy Tan Univ	Software	2013 …	ABET (planned)
…				

TO SUMMARIZE:

CDIO aims to educate students who are able to:

- **Master a deeper working knowledge of the technical fundamentals**
- **Lead in the creation and operation of new products, processes, and systems**
- **Understand the importance and strategic impact of research and technological development on society**
- **To learn more, visit www.cdio.org or read *Rethinking Engineering Education: The CDIO Approach, 2nd ed* by Crawley, Malmqvist, Östlund, Brodeur & Edström, 2014**



Thank you for listening!

Any questions or comments?